LHC Search and Constraint on NLSP Gluino Model

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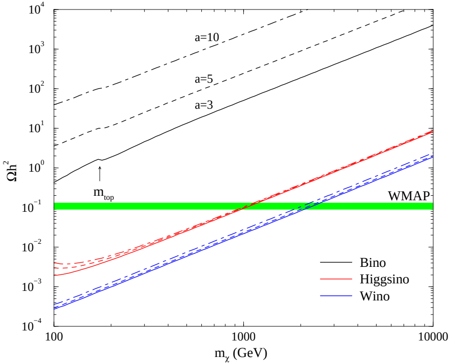
based on works:
M. Adeel Ajaib, TL, Qaisar Shafi, Kai Wang, JHEP 1101 (2011) 028
M. Adeel Ajaib, TL, Qaisar Shafi, arXiv:1107.2573 [hep-ph]

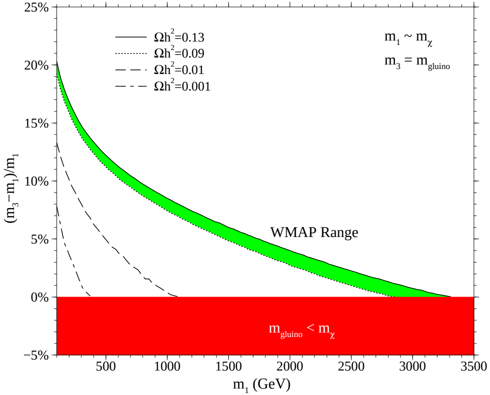
Motivation

- dark side of MSSM: conserved R parity, LSP, dark matter
- lightest neutralino dark matter (bino, wino, higgsino): WMAP bound on $\tilde{\chi}_1^0$ LSP relic abundance



all other superparticles are assumed to have mass larger than $m_{SUSY} \approx a \cdot m_\chi$, with $a = 3, 5, 10$. S.Profumo and C.E.Yaguna, Phys. Rev. D 70, 095004 (2004).

- overproduction of relic abundance from light bino-like LSP annihilation: compensated by co-annihilation effect with a strongly-interacting particle, such as gluino, $\tilde{g}\tilde{\chi}_1^0 \to q\bar{q}, \tilde{g}\tilde{g} \to gg, q\bar{q}$ S.Profumo and C.E.Yaguna, Phys. Rev. D 69, 115009 (2004).



gluino-bino co-annihilation requires: $\dfrac{M_{\tilde{g}} - M_{\tilde{\chi}_1^0}}{M_{\tilde{\chi}_1^0}} \lesssim 20\%$, NLSP gluino

- The NLSP gluino is relatively light and its production rate can be large at the LHC, even at the early stage.
- With a NLSP gluino, the chargino as well as squarks are absent in the gluino cascade decay. The conventional search strategies (such as $\tilde{\chi}^{\pm}\tilde{\chi}^{\pm}$ or energetic jets and large missing energy) do not work here and the NLSP gluino can evade the bounds from direct searches at the Tevatron and current LHC.

NLSP Gluino Models

- The relations between gaugino masses will be crucial in understanding the nature of supersymmetry breaking and of the underlying theory at ultra-high energy scale. With NLSP gluino, one must invoke non-universal gaugino masses at M_{GUT} beyond conventional mSUGRA model ($M_3 : M_2 : M_1 \sim 6 : 2 : 1$).

- Non-universal gaugino masses are accomodated in GUT models with non-singlet F-term vevs S.P.Martin,Phys.Rev.D79(2009)095019; D.Feldman,Z.Liu,P.Nath, Phys.Rev.D80(2009)015007

  or enlarged supersymmetric gauge group $SU(5) \times SU(3)_{Hypercolor}$ N.Arkani-Hamed,H.C.Cheng,T.Moroi,Phys.Lett.B387(1996)529

  or partial unified model $SU(4)_c \times SU(2)_L \times SU(2)_R$(4-2-2),...

- 4-2-2 model: $SU(4)_c \times SU(2)_L \times SU(2)_R$ broken down to $SU(3)_c \times SU(2)_L \times U(1)_Y$ at GUT scale
  $\Rightarrow I_Y = \sqrt{\frac{3}{5}} I_{3R} + \sqrt{\frac{2}{5}} I_{BL}$
  (I_{3R}, I_{BL} are the diagonal generators of $SU(2)_R, SU(4)_c$)

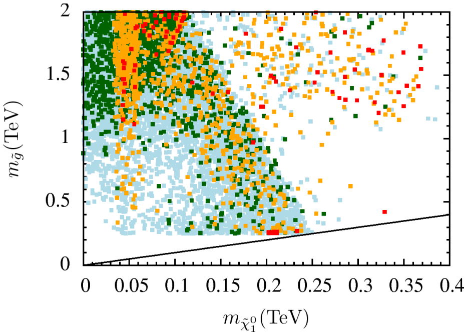
  $$\Rightarrow \frac{1}{\alpha_Y(M_{GUT})} = \frac{3}{5}\frac{1}{\alpha_{I_{3R}}(M_{GUT})} + \frac{2}{5}\frac{1}{\alpha_{I_{BL}}(M_{GUT})}$$

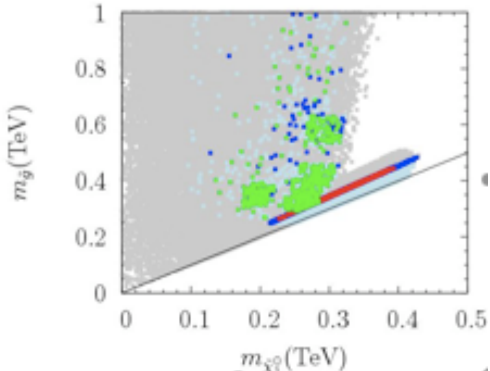
  $\Rightarrow M_1 = \frac{3}{5} M_2 + \frac{2}{5} M_3$: gaugino non-universality

- matter fields: $\psi_i = (4, 2, 1)$ and $\psi_i^c = (\bar{4}, 1, 2)$
  MSSM Higgs: $H = (1, 2, 2)$
  third family Yukawa coupling $\psi \psi^c H \Rightarrow Y_t = Y_b = Y_\tau = Y_{\nu_\tau}$:
  Yukawa unification

I.Gogoladze,R.Khalid and Q.Shafi, Phys. Rev. D 79 (2009) 115004;I.Gogoladze,R.Khalid and Q.Shafi, Phys. Rev. D 80 (2009) 095016;I.Gogoladze,R.Khalid, S.Raza and Q.Shafi, arXiv:1008.2765[hep-ph].

- NLSP Gluino solutions
  in 4-2-2 model
  $\mu < 0$ (top)
  $\mu > 0$ (bottom)





	Model A ($\mu > 0$)	Model B ($\mu < 0$)
m_0 (GeV)	14110	1513
M_1 (GeV)	499.54	-479.49
M_2 (GeV)	832.03	-845.5
M_3 (GeV)	0.7945	69.53
$\tan\beta$	50.82	47.7
A_0	-34551.2	-1668.84
m_{H_u} (GeV)	6092.74	492.41
m_{H_d} (GeV)	14194.5	1071.75
$M_{\tilde{g}}$ (GeV)	329	261
$M_{\tilde{\chi}_1^0}$ (GeV)	284	207
$M_{\tilde{b}_1}$ (GeV)	5294	950
$\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0)$	76.3%	50.8%

Table: Model parameters at GUT scale (above double line) and low scale (below double line) for two benchmark models. Note that the bino component of $\tilde{\chi}_1^0 \geq 99.9\%$.

NLSP Gluino Decay

M.A.Ajaib, T.Li, Q.Shafi and K.Wang, JHEP 1101(2011) 028.

- NLSP gluino decay: $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0, b\bar{b}\tilde{\chi}_1^0, g\tilde{\chi}_1^0$
- The three-body decays will be suppressed if the scalar masses are too large, or due to phase space if $m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$ is too small. In this model (422), displayed points have ~ 1 TeV sbottom mass and $m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$ between 40 and 60 GeV. For this region, three-body decay $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ dominates.
- If either decay $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ or $\tilde{g} \to g\tilde{\chi}_1^0$ dominates, the final state jets are typically as soft as those from parton shower. In this case the gluino decay very likely gets buried in huge QCD background.
- Our study focused on a different region where the gluino three-body decays into two b jets dominate. Tagging jet with decaying B mesons will significantly reduce the QCD jets background.

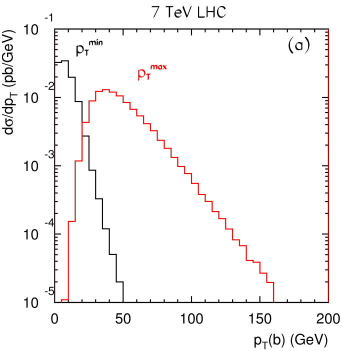
NLSP Gluino Search at the LHC

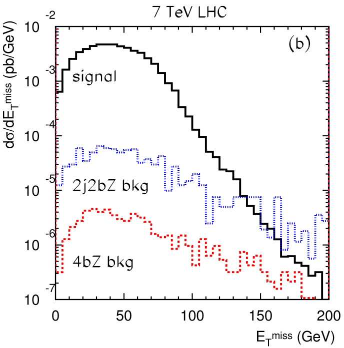
M.A.Ajaib, T.Li, Q.Shafi and K.Wang, JHEP 1101(2011) 028

- $pp \to \tilde{g}\tilde{g} \to b\bar{b}b\bar{b} + \not{E}_T$ @ 7 TeV LHC
- bkg: $b\bar{b}b\bar{b}$, $jjb\bar{b}$, $b\bar{b}b\bar{b}Z$, $jjb\bar{b}Z$ with $BR(Z \to \nu\bar{\nu}) = 20\%$
- selection cuts:

  4 b-tagged jets with $p_T > 15$ GeV,$|\eta_j| < 2.0$,$\Delta R_{jj} > 0.4$,
  $\epsilon_b = 50\%$, $\epsilon_{\not{b}} = 1/30$, $\not{E}_T > 40$ GeV

CDF Collaboration,D.Acosta et al.,Phys.Rev.Lett.95(2005)131801; ATLAS TDR, CERN-LHCC-99-14





$\sigma(\mathrm{fb})$@ 7 TeV LHC	Model A	Model B	$b\bar{b}b\bar{b}$	$b\bar{b}b\bar{b}Z$	$jjb\bar{b}Z$
basic cuts and 4b tagging	143	271	157×10^3	0.55	4.2
$\not{E}_T > 40$ GeV	59	140	–	0.4	3.3

After selection cuts, we expect negligible background events and $\gtrsim O(10)$ events for benchmark points with 1 fb^{-1} luminosity @ 7 TeV LHC.

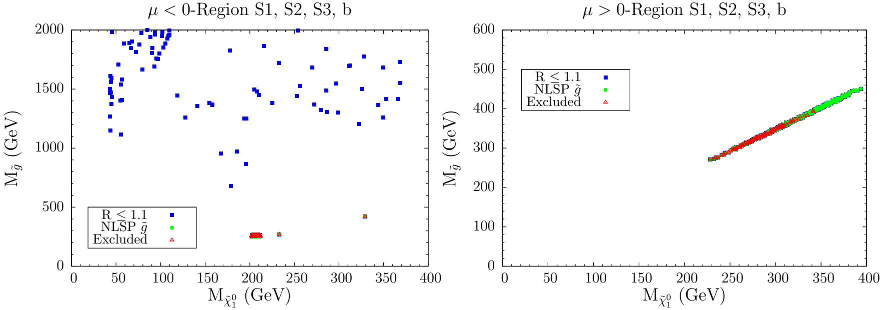
LHC Constraints on NLSP Gluino (4-2-2)

M.A.Ajaib, T.Li and Q.Shafi, arXiv:1107.2573 [hep-ph]

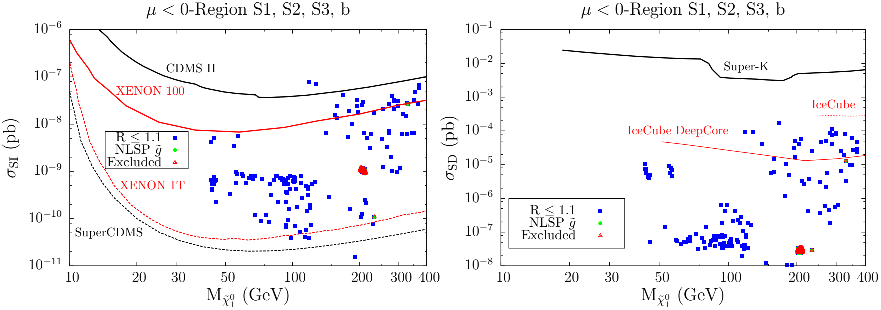
	S1	S2	S3	b
Number of jets	≥ 2	≥ 3	≥ 4	≥ 3
Number of b-jets	0	0	0	≥ 1
Leading jet p_T (GeV)	> 130	> 130	> 130	> 120
Other jets p_T (GeV)	> 40	> 40	> 40	> 30
$\Delta\phi(\vec{p}_T^{\rm miss}, j_{1,2,3})$	> 0.4	> 0.4	> 0.4	> 0.4
m_{eff} (GeV)	> 1000	> 1000	> 1000	> 600
$\not{E}_T$ (GeV)	> 130	> 130	> 130	> 100
$\not{E}_T/m_{eff}$	> 0.3	> 0.25	> 0.25	> 0.2
ATLAS $\sigma_{\rm exp}$ (pb)	35	30	35	0.32

Table: Summary of selection cuts and 95% C.L. upper limits on effective cross section for non-SM processes for signal region S1, S2, S3 with 165 pb^{-1} luminosity, and region b with 35 pb^{-1} luminosity, following ATLAS data analyses.

ATLAS Collaboration, arXiv: 1102.5290 ,1103.4344 [hep-ex]



NLSP gluino masses below $\sim$ 350 GeV in 4-2-2 model are excluded by the LHC data.



LHC constraints on the spin-independent (spin-dependent) neutralino-nucleon cross section are significantly more stringent than the bounds from XENON 100/CDMS (IceCube DeepCore).

Summary and Discussion

- To accommodate correct relic abundance of bino dark matter, gluino co-annihilation is an important scenario which induces NLSP gluino solution.
- A new search for NLSP gluino involving multi-b final states, arising from the three-body decay $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$
- For the 7 TeV LHC with 1 fb^{-1} integrated luminosity, the number of signal events for 4-2-2 model is $\gtrsim O(10)$, to be compared with negligible SM background events.
- NLSP gluino masses below $\sim$ 350 GeV in 4-2-2 model are excluded by LHC data.
- LHC constraints on the neutralino-nucleon cross section are more stringent than current dark matter direct detection experiments.

- Public LHC searches not designed to probe NLSP gluino
- "Squashed" spectra and scenarios evade the bounds: miss something in low energy?
- Need dedicated study: improved b-tagging to probe low pt, low $\not{E}_T$ multi-b jets signature; may use hard ISR (monojet+missing energy result at 1 fb^{-1})

  ATLAS Collaboration, EPS-HEP2011

Thank You!